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(71) Applicant: A. AHLSTROM CORPORATION [FI/FI]; SF-29600 Noormarkku (FI).

(72) Inventor: TANG, John, T. ; 13236 Bavarian Drive, San Diego, CA 92129 (US).

(74) Agent: BLOMQUIST, Tuula; A. Ahlstrom Corporation, Patent Department, P.O. Box 18, SF-48601 Karhula (FI).

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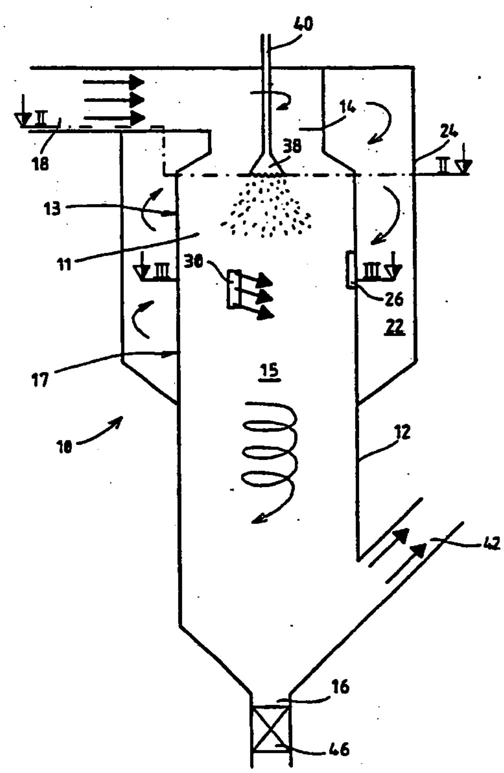
(54) Title: MULTI-STAGE VORTEX REACTOR

(57) Abstract

A multi-stage vortex reactor for contacting a gas stream with a gas, a fluid or other stream, comprising a housing having end walls and a peripheral side wall defining an elongated generally cylindrical vortex chamber having an inlet end and an outlet end, a first inlet in the inlet end of the vortex chamber for introducing a first gas stream in a swirling motion into the vortex chamber, a second inlet for introducing a second gas stream adjacent the inlet end of the vortex chamber for flowing around at least a part of the vortex chamber for separating the first stream from said chamber walls, a supply duct divides a gas stream into at least a first gas stream and a second gas stream and introduces the first gas stream into the first inlet in the vortex chamber and the second gas stream into the second inlet, an injector for introducing a liquid into the first gas stream in the vortex chamber, and an outlet for continuously removing gas from the vortex chamber.

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# MULTI-STAGE VORTEX REACTOR

## BACKGROUND OF THE INVENTION

The present invention relates to vortex reactors and pertains particularly to an improved method and apparatus for enhancing the process reaction between gases and reactants (in the form of particles or liquid droplets).

Reactions between gases and particles or slurry droplets are common in many industrial processes. In many instances, the particles or slurry droplets are sticky and are troublesome, because they can stick to the reactor walls during the course of reaction and processing through the reactor. One prior art approach to reducing or eliminating this problem is the provision of very large reaction vessels to prevent the deposition of sticky particles on the reactor walls. Another approach is to apply very high energy to the slurry atomization in order to prevent the solid deposition from happening.

Current dry processes for flue gas desulfurization with atomized lime slurry require high energy for slurry atomization or a long reactor vessel to prevent the sticky lime slurry particles from depositing on the reactor wall and plugging up the reactor ducts.

It is, therefore, desirable that an improved reactor vessel and process be available for controlling the reaction between gases and reactants (in the form of particles or liquid droplets) that will prevent the particles from sticking to the vessel walls.

SUMMARY AND OBJECTS OF THE INVENTION

It is, therefore, the primary object of the present invention to provide an improved reactor vessel and process for controlling the reaction between gases and reactants (in the form of particles or liquid droplets) in order to prevent the particles from sticking to the vessel walls.

In accordance with the primary aspect of the present invention, a vortex reactor is provided with multiple stage gas entrances for promoting the mixing between gases and slurry droplets and/or solid particles, and to prolong reacted particles in reactor residence time and prevent sticky particles from reaching the reactor wall before drying out and/or becoming free of stickiness. The process, in accordance with the invention, includes dividing the gases into first and second flows, with the fluid injection into the first flow, and introducing of the second flow at a position downstream from the first flow at an angle that enhances reaction and reduces the rate of travel of the particles toward the reactor wall.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects and advantages of the present invention will become apparent from the following description when read in conjunction with the drawings wherein:

Fig. 1 is a side elevation view schematically illustrating a multi-stage vortex reactor in accordance with the invention;

Fig. 2 is a top plan view in section schematically illustrating the gas flow and inlet arrangement in accordance with a first embodiment of the invention;

Fig. 3 is a top plan view in section schematically illustrating the gas movement in the reactor in accordance with the embodiment of Fig. 2;

Fig. 4 is a view like Fig. 2 of a second embodiment;

Fig. 5 is a view like Fig. 3 of the embodiment of Fig. 4.

Fig. 6 is a partial side elevation view in section illustrating another embodiment of the invention;

Fig. 7 is a view like Fig. 3 of the embodiment of Fig. 6; and

Fig. 8 is a view taken on line VIII-VIII of Fig. 6.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Fig. 1 of the drawings, there is schematically illustrated a multi-stage vortex reactor, in accordance with the present invention, designated generally by the numeral 10. The reactor comprises an elongated cylindrical first housing 12, defining a reactor with a vortex chamber 15, having an inlet 14 at an upper end and an outlet duct 16 at a lower end. At the upper or inlet end 11 of the reactor, there is provided a first reactor gas inlet duct 18 for the introduction of a first stream of gas.

Referring to Fig. 2, the first stream of gas 45 enters via inlet duct 18 at a tangent to the circular opening of the inlet 14 in the upper end of the vortex chamber, causing the inlet gases to swirl around in a counter-clockwise direction. As also illustrated in Fig. 2, a second gas inlet duct 20 is provided for the introduction of a second gas 47 into an annular chamber 22, defined by an annular housing 24 surrounding the inlet end of the reactor housing. The annular chamber 22, defined by the outer housing 24, carries the second stream of gas in a swirling motion around the outside wall of the reactor housing 12, counter to the first inlet stream. The second gas stream 47 is in heat exchanger contact, with the peripheral wall 13 of the vortex chamber heating or cooling

said wall. The second stream also flows axially along the reactor, wherein it enters the reactor at inlet openings 26, 28 and 30.

These inlet openings are staged circumferentially around and axially along the peripheral side wall 17, as illustrated in Figs. 1 and 2, such that the gas flows along and around the reactor prior to entering the housing. The inlets for the second gas stream have inlet angle directing devices in the form of outward extending guide plates or baffles 32, 34, and 36 that direct the gas into the vortex chamber at a particular tangential angle for flowing around at least a part of inner walls of the vortex chamber, which aids in controlling the rate of outer movement of the solid or slurry particles within the reactor chamber. Additionally, the second gas stream exchanges heat to the peripheral wall and raises the wall temperature that prevents sticky particles or fluid droplets from depositing at the wall.

Referring still to Fig. 1, a fluid injector 38 at the center inlet of the vortex chamber introduces a fluid liquid or a slurry into the chamber from a suitable source via a conduit 40. This slurry is mixed with and carried along with the first stream of gases that enter into the vortex chamber via inlet duct 18 and flow in a

counter-clockwise direction in the chamber. Other gases, liquids, or solid particles may also be introduced into the chamber at this point. The term "fluid" includes gases and liquids which may or may not contain solid particles. The second stream of gas that enters the chamber is introduced at the outer surface of the chamber flowing along the wall (Fig. 3) in the opposite direction, separating the first stream and the sticky slurry particles from the inner surface of the wall until the particles have dried and moved substantially to the bottom of the reactor. As shown in Fig. 3, the counter flowing streams create small swirling currents between them as they flow along the chamber of the reactor. This counter flow arrangement prevents sticky liquid or slurry droplets from reaching the reactor wall.

At the bottom of the reactor, there is provided a solid outlet 16 (Fig. 1) and a gas outlet duct 42 for drawing of the cleaned gas from the stream. Solids that have separated from the gases drop to the bottom of the reactor and are drawn off through a suitable rotary valve 46 in the solids outlet duct 16, as illustrated.

A damper 48 and a partition 44 in the inlet duct controls the proportion of the volume of the inlet gases 45, 47 between the inlet ducts 18 and 20. When the damper is in the

unrestricted position, the division of flow will be in proportion to the size of the respective duct. When the damper 48 is in a restricted position partially across the the duct passage, the flow in duct 20 will decrease and that in duct 18 will increase in proportion to the restriction. Thus, the damper may be used to adjust the flow split between the volume of first and second gas streams 45 and 47 in certain proportion for optimizing reactions as well as fluid mixing pattern in the reactor.

This structure and process enhances and promotes the mixing between the gases introduced into the chamber and the slurry droplets and solid particles. The process creates a strong vortex of the gas and prolongs the contact and reactant residence time and prevents the sticky particles from reaching the reactor walls.

In other applications when there is a need to recover reactants upon completing the reaction, it is preferred to have both gas streams whirling in a similar direction in the reactor. Referring to Fig. 4, wherein like numbers identify the same elements and modifications are identified by the same numbers primed, a flow arrangement is illustrated wherein the gas flow from both gas inlet ducts are in the same direction. In this arrangement, the first inlet duct 18' enters the circular opening of the inlet 14

of the vortex chamber on the same side as the second duct 20. Thus, the first and second streams are flowing in a common clockwise direction, with less turbulence as illustrated in Fig. 5. This approach promotes the particles' radial movement for its removal at the reactor bottom.

Referring to Fig. 6, a further embodiment is illustrated wherein a main housing 50, as in the previous embodiments, defines a vortex chamber 52 into which gasses and the like are introduced. The vortex chamber has a first inlet 54 wherein a first gas stream is introduced, with a liquid or slurry injector 56 for introducing liquid or the like into the stream. The lower or bottom portion of the reactor is constructed the same as in the prior embodiments. An outer housing 58 forms an annular chamber 60 as in the prior embodiments.

Referring to Fig. 7, a gas stream is introduced via a duct 62, which is split into ducts 64 and 66, with the first duct directing gases into the inlet 54, and the second introducing gas into the annular chamber 60. A damper 68 controls the flow between ducts 64 and 66. The roof of the housing 50 is provided with a plurality of triangular shaped inlet opening slots 70, 72, 74, and 76 (Fig. 8) into the chamber 52 from the uppermost part of the

annular chamber 60. A portion of the gas stream entering chamber 60 flows trough the opening slots 70-76, forming a stream of hot gas along the top of the chamber 52 protecting the surface of the top of the chamber from accumulation of reagent droplets. The remainder of the gas flows down along the annular chamber 60 along side of the chamber 52 along housing wall 50 and enters the chamber 52 via a plurality of inlets (only one 78 shown) as in the prior embodiments.

This apparatus and process can be applied to many chemical reaction processes in industry. One particular application is to flue gas desulfurization with injection of slurry droplets or the like. Another application of the reactor and of the process is that to processes involving gas and sticky particles reactions. This can include any number of different compositions of gas particles and the like.

Another process to which the present reactor and processes may be applied is that to the combustion of coal slurry fuel mixture in small furnaces.

In carrying out the process as above described, the steps include dividing the gas stream into a first portion directed directly to the reactor, and diverting a second portion of the gas to the reactor via wall inlets in the

region where the solids and the droplets are being introduced to the reactor. The gas forms a strong vortex in its course of traveling downward and provides high slip velocity. Slip velocity is a relative velocity between gas and solid particles or slurry droplets. This promotes heat and mass transfer between the gas and reactor particles or slurry droplets, and helps to shorten the reaction time requirement as well as dry out time. Also the gas vortex prolongs particles or slurry droplet staying time in the reactor.

The second portion of the gas stream is directed toward the outer annular region of the reactor and enters the reactor via the various opening slots located axially along and radially along the reactor wall. This provides additional mixing and turbulence at various distances in the reactor down stream and prevents still sticky particles from reaching, adhering and depositing on the reactor walls.

The direction of the gas swirling in the upper region of the reactor from the second stream can be selected to be either in the same direction or opposite direction to that of the primary stream in the reactor. This could depend on a number of factors, including the types of process application, the degrees of particle stickiness and the desire for particle separation. With the opposite

direction of entrance into the reactor, as shown in Figs. 2 and 3, a deposition of still sticky particles on the reactor wall can be avoided.

Referring to Fig. 4, it is seen that the primary gas duct is divided, as in the previous embodiment, with the gas streams moving however in the same clockwise direction in the reactor. In this arrangement, the primary stream is fed into the reactor to move in a clockwise direction, as shown in Fig. 4. The second gas stream, which is controlled by a damper for controlling the proportion of the volume between the first and second streams, is also introduced into the outer chamber in the same direction, wherein it moves along and enters the reaction chamber in the same direction, as shown in Fig. 5. This arrangement of the primary and secondary gas flow in the same direction aids in solids separation from the gas stream for its recovery or removal.

The Fig. 6-8 embodiment or feature of triangular slots or openings in the upper or inlet end wall of the reactor chamber can be embodied or combined with either Figs. 2 or 4 directions of flow. This features can aid in controlling the outward velocity of the liquid and solids introduced into the chamber.

While I have illustrated and described my invention by means of specific embodiments, it is to be understood that numerous changes and modifications may be made therein without departing from the spirit and scope of the invention as defined in the appended claims.

Claims

1. A multi-stage vortex reactor, for enhancing the mixing of a material into a gas stream thereby forming a mixture and for maintaining the mixture out of contact with walls of the vortex reactor, comprising

- a housing having a peripheral side wall defining an elongated generally cylindrical vortex chamber having an inlet end and an outlet end; and
- first inlet means in the inlet end of the vortex chamber for introducing a first gas stream into the vortex chamber; and
- outlet means at the outlet end for continuously removing gas from the vortex chamber;

characterized by

- second inlet means (26,28,30, 70,72,74) in a peripheral wall (13) adjacent the inlet end (11), for introducing a second gas stream into the vortex chamber (15) adjacent the inlet end of the vortex chamber for flowing around at least a part of the inside of the peripheral wall for at least partially separating the first gas stream from the peripheral wall;
- means (44,48,68) for dividing a gas stream into at least a first gas stream (45) and a second gas stream (47) and for introducing the first gas stream into the first inlet means (14,20) in the vortex chamber and the second gas stream into the second inlet means (26,28,30); and
- means (38,40) for introducing a material into the first gas stream in the vortex chamber for mixing therewith.

2. A multi-stage vortex reactor as recited in claim 1, characterized by

- the first inlet means including means (20) for creating a generally rotational motion to the first gas stream as it is introduced into the first inlet means for giving the gas a long residence time in the vortex reactor.

3. A multi-stage vortex reactor as recited in claim 1, **characterized by**
- the second inlet means (26,28,30) comprising an opening through a peripheral side wall (17) in the form of a vertical slot for introducing the second gas stream (47) into the vortex chamber along the wall thereof in a circular flow around the axis of the vortex chamber.

4. A multi-stage vortex reactor as recited in claim 1, **characterized by**
- the second inlet means (26,28,30) comprising a plurality of axially and angularly distributed gas inlet openings (26,28,30) through the peripheral side wall (17) for introducing the second gas stream (47) into the vortex chamber counter to the flow of the first gas stream (45).

5. A multi-stage vortex reactor as recited in claim 4, **characterized by**
- the gas inlet openings (26,28,30) containing a guide plate (32,34,36) for introducing the second gas stream tangentially into the vortex chamber.

6. A multi-stage vortex reactor as recited in claim 1, **characterized by**
- the second inlet means (26,28,30) containing a guide plate forming an angle with the peripheral side wall (17) for guiding the second gas stream in a controlled direction into the vortex chamber.

7. A multi-stage vortex reactor as recited in claim 1, **characterized by**
- the means (44,48,68) for dividing the gas stream comprising a damper (48,68) for regulating the proportion of first gas stream to second gas stream.

8. A multi-stage vortex reactor as recited in claim 1, **characterized by**

- the vortex reactor including an annular housing means (22) surrounding at least part of the peripheral side wall (17) at the inlet end (11) of the vortex chamber and providing a flow path for the second gas stream around at least a part of the vortex chamber.

9. A multi-stage vortex reactor as recited in claim 1, **characterized by**
- the second inlet means (70,72,74) comprising a plurality of radially and angularly distributed gas inlet openings (70,72,74) through an end wall at the inlet end of the vortex chamber.

10. A method of mixing a fluid stream into a gas stream, utilizing a vortex reactor, having a vortex chamber with a generally cylindrical peripheral wall, an inlet end and an outlet end, by
- introducing a gas stream through an inlet duct into the vortex chamber at the inlet end of the vortex reactor and
- continuously removing gas through the outlet end,
**characterized by**
- dividing a gas stream into at least a first and a second gas stream;
- introducing the first gas stream through an inlet duct into the vortex chamber at the inlet end of the vortex reactor;
- introducing a fluid stream into the vortex chamber at the inlet end ot the vortex reactor for mixing the fluid stream into the first gas stream;
- directing the second gas stream into an annular housing at least partly surrounding the peripheral wall in the inlet end of the vortex reactor; and
- introducing gas from the second gas stream in the annular housing through at least one opening in the peripheral wall into the vortex chamber.

11. A method as recited in claim 10, **characterized by**

the second gas stream being directed in a path surrounding the upper part of the peripheral wall of the vortex chamber in heat exchange contact with the peripheral wall.

12. A method as recited in claim 11, characterized by the second gas stream heating the upper part of the peripheral wall.

13. A method as recited in claim 11, characterized by the second gas stream cooling the upper part of the peripheral wall.

14. A method as recited in claim 10, characterized by the first gas stream being introduced tangentially into the vortex chamber for creating a generally circular gas flow in the vortex chamber.

15. A method as recited in claim 14, characterized by the fluid stream being introduced substantially into the middle of the circular gas flow at the inlet end of the vortex reactor for providing good contact between fluid mixed into the gas flow.

16. A method as recited in claim 14, characterized by the second gas stream being introduced tangentially through a plurality of openings in the peripheral wall into the vortex reactor and in the same direction as the circular gas flow in the vortex reactor for providing a shielding gas flow at the outer periphery inside the vortex chamber for preventing sticky particles from depositing on the peripheral wall.

17. A method as recited in claim 10, characterized by the second gas stream being introduced tangentially through a plurality of openings in the peripheral wall into the vortex reactor and substantially in the opposite direction to the gas flow in the vortex chamber for improving the mixing of gas and fluid.

18. A method as recited in claim 10, characterized by the fluid stream containing fine dispersed liquid droplets.

19. A method as recited in claim 10, characterized by the fluid stream containing fine dispersed solid particles.

20. A method as recited in claim 10, characterized by the fluid stream containing gaseous compounds.

21. A method as recited in claim 10, characterized by dividing the gas stream into a first larger gas stream and a second smaller gas stream in front of the inlet duct to the vortex chamber.

22. A method as recited in claim 10, characterized by introducing the second gas stream through openings in the peripheral wall into the vortex chamber for gradually contacting the second gas stream with the first gas stream.

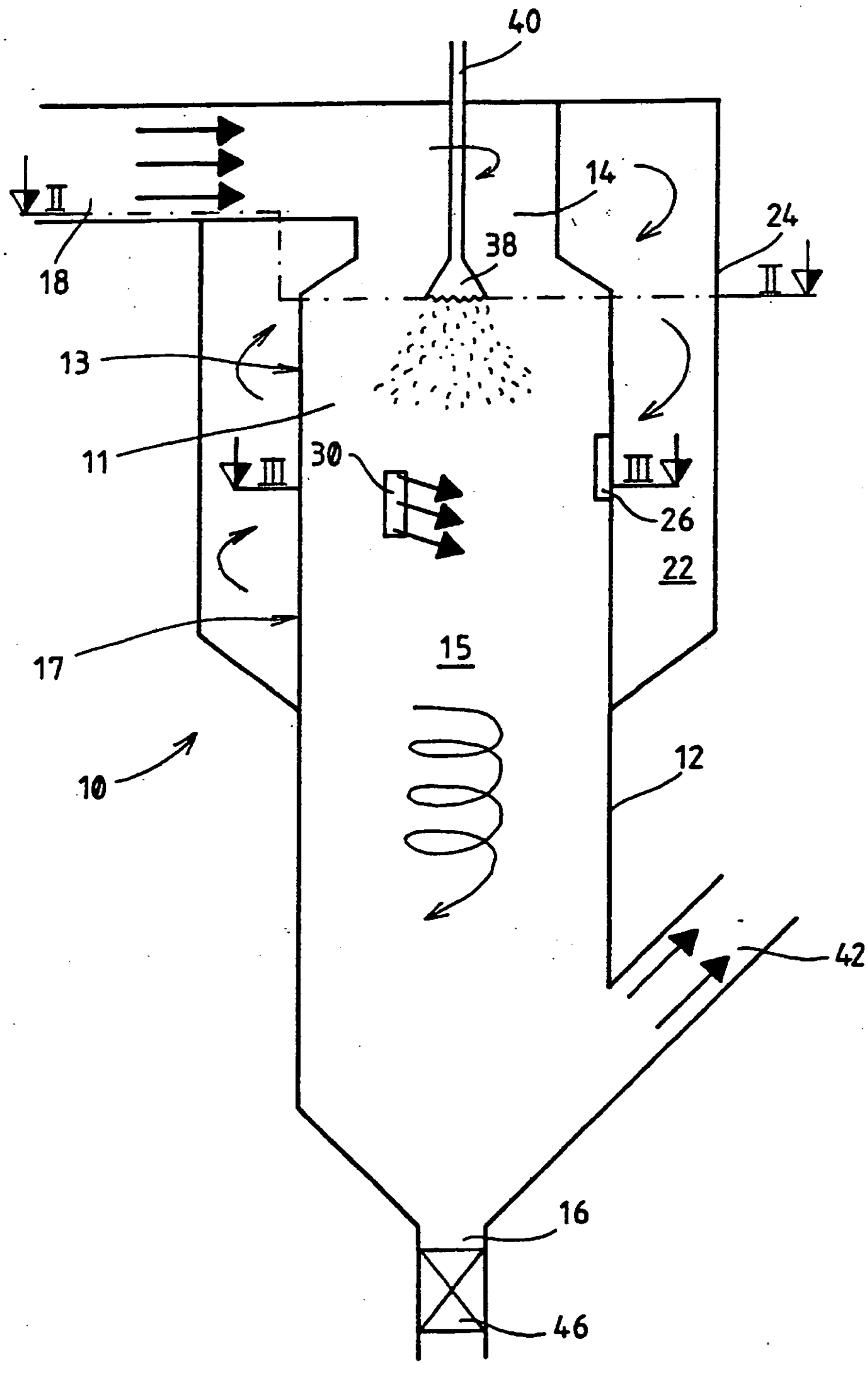


FIG.1

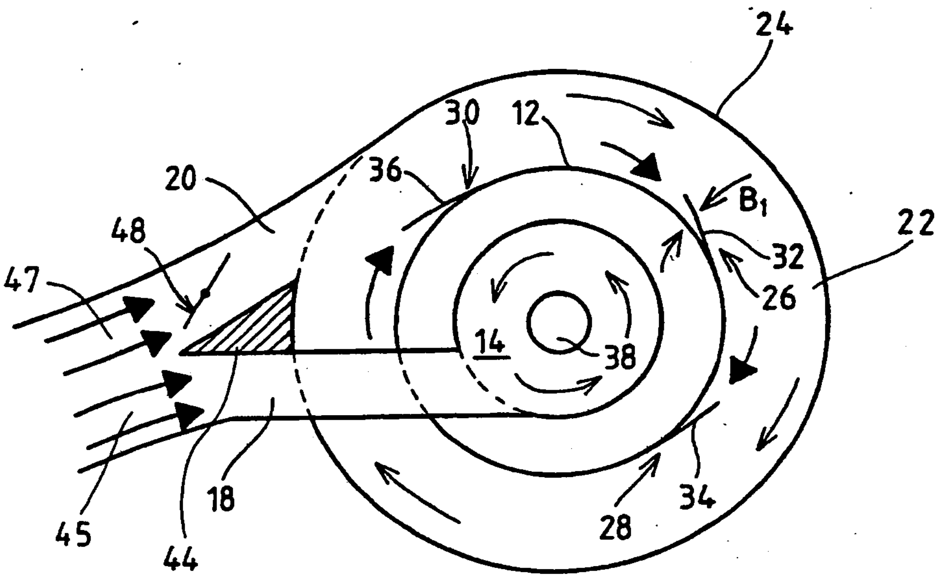
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FIG.2

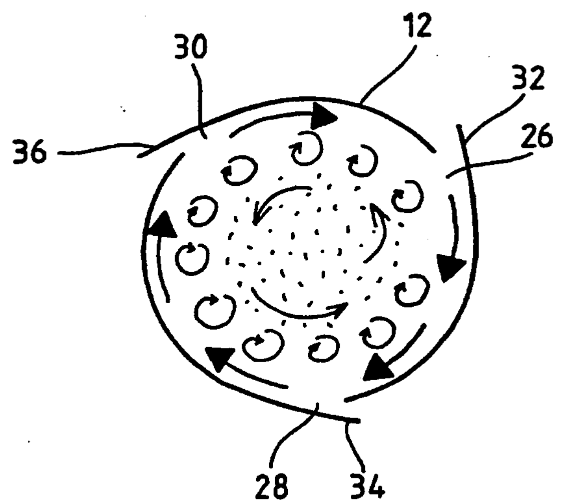
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FIG.3

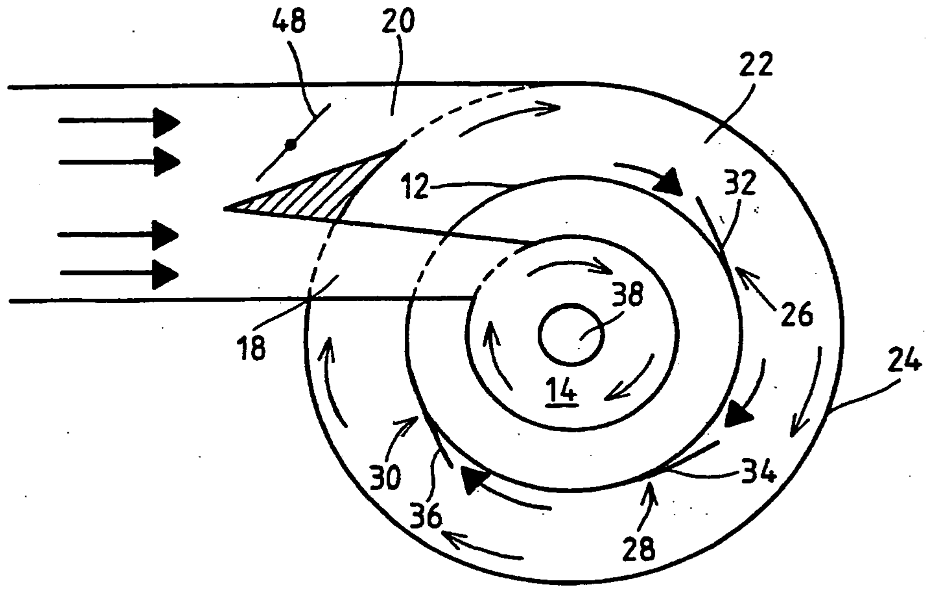


FIG.4

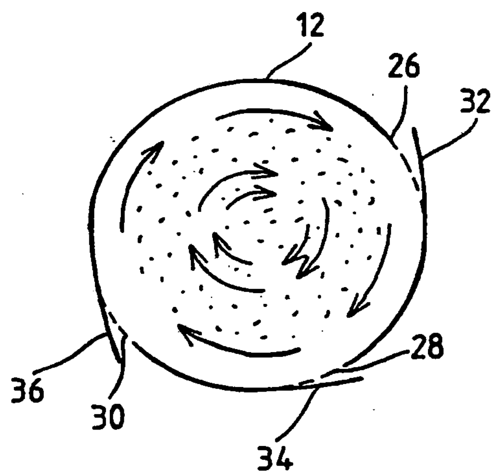


FIG.5

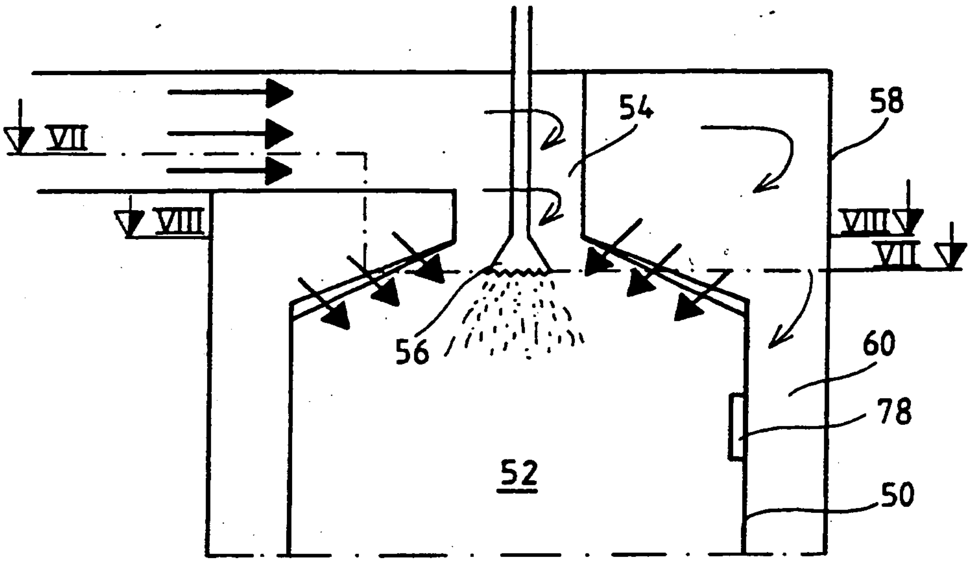
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FIG.6

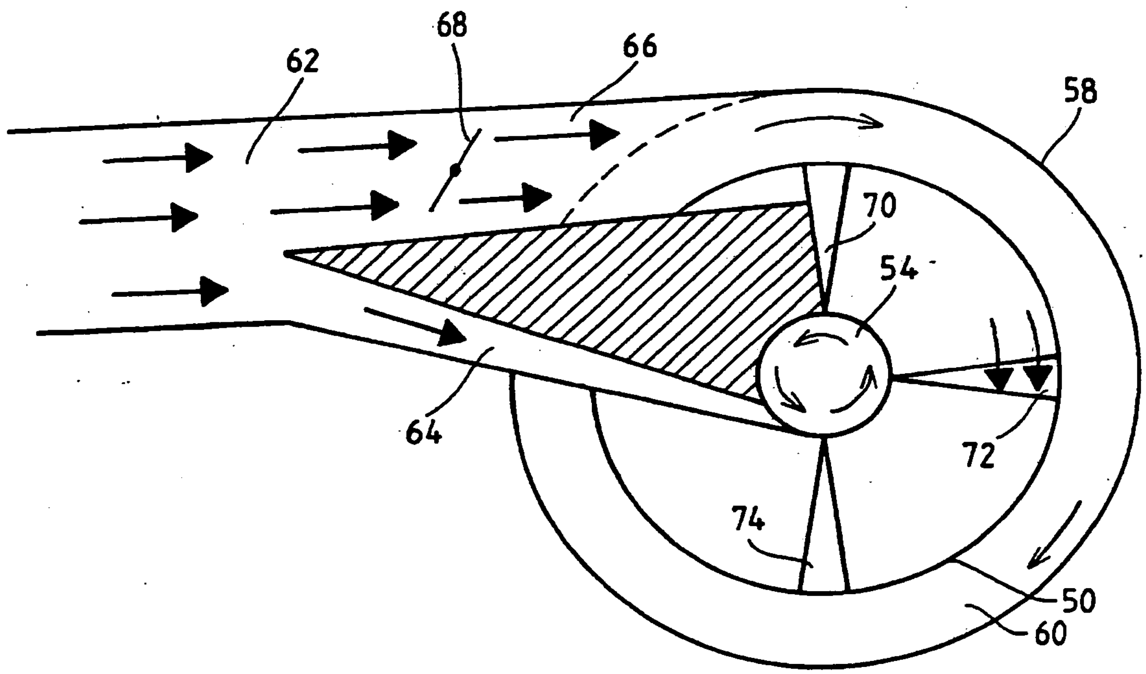
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FIG.7

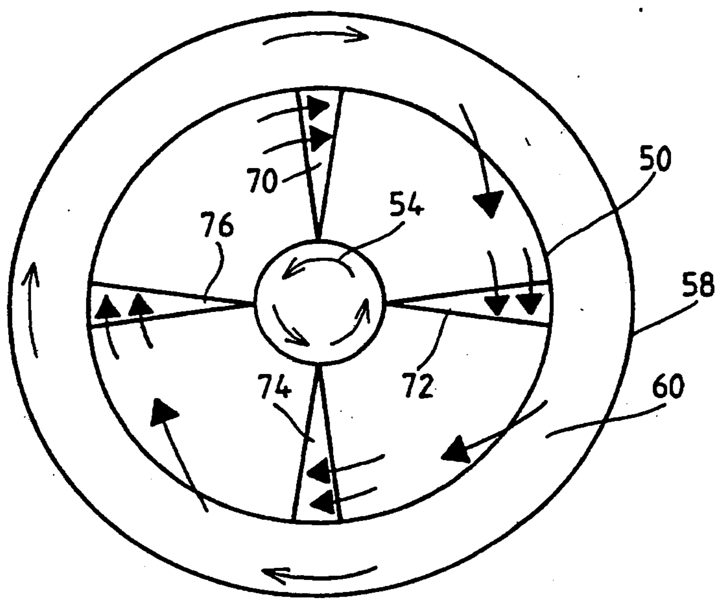


FIG. 8

# INTERNATIONAL SEARCH REPORT

International Application No PCT/FI 90/00128

**I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]**

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: B 01 J 8/14

**II. FIELDS SEARCHED**

Minimum Documentation Searched[7]

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Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

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**III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]**

| Category * | Citation of Document,[11] with indication, where appropriate, of the relevant passages[12] | Relevant to Claim No.[13] |
|---|---|---|
| A | DE, A1, 3520032 (MAJOROS, ISTVÅN) 4 December 1986, see the whole document -- | 1-22 |
| A | US, A, 4736527 (TUTOMU IWAMOTO ET AL) 12 April 1988, see the whole document -- | 1-22 |

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**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 28th June 1990 | 1990 -07- 20 |
| **International Searching Authority** | **Signature of Authorized Officer** |
| SWEDISH PATENT OFFICE | Eva Iversen Hasselrot |

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## ANNEX TO THE INTERNATIONAL SEARCH REPORT
## ON INTERNATIONAL PATENT APPLICATION NO.PCT/FI 90/00128

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
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| | | JP-A- 59125740 | 84-07-20 |
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| | | JP-A- 59125742 | 84-07-20 |